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AN UPDATED LOOK AT SOME SEVERE WEATHER FORECAST PARAMETERS

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1. INTRODUCTION

One of the primary missions of National Weather Service (NWS) forecasters is the issuance of tornado and severe thunderstorm warnings. Warnings are issued for imminent or occurring severe weather. They are typically issued for small geographical areas (usually 1 or 2 counties) and for a duration of an hour or less. Tornado and severe thunderstorm watches for the entire country are issued by the NOAA/NWS Storm Prediction Center. Watches are issued for large geographical areas (parts of several states) with lead times of several hours. These watches alert the public that general weather conditions are favorable for severe thunderstorms or tornadoes. The identification of the synoptic and mesoscale meteorological conditions that are associated with tornadoes and severe thunderstorms typically is the first step in the watch and warning process. Forecasters routinely make subjective assessments of convective potential for their forecast area based on the values of various atmospheric parameters and indices. If convection is possible, forecasters must decide whether it will be severe or non-severe; and if severe thunderstorms are possible, they must determine if the primary threat will be large hail, damaging winds, tornadoes, excessive rainfall, or all four. The specific parameter values which influence certain decisions may vary from person to person depending on a forecaster's geographic location, experience, and scientific understanding of the physical processes associated with thunderstorm development and evolution. Because of the subjective nature of the decision making process, the results may not be consistent.

In Maglaras and LaPenta (1997) (hereafter referred to as ML97), the general atmospheric conditions that were associated with tornadoes, severe thunderstorms and non-severe thunderstorms in New York were examined. ML97 describes the development of a regression equation (Table 1) to make conditional forecasts of thunderstorm severity, given the occurrence of thunderstorms. The equation provides guidance on forecasting tornadic, major severe thunderstorm, minor severe thunderstorm and non-severe thunderstorms days in New York. Major severe weather days were defined as those days with 10 or more severe weather reports in the northeastern United States, and minor severe weather days were defined as those days with less than 10 events. The northeastern United States includes New York, New England, Pennsylvania and New Jersey. The study was based on data from 148 individual days. These data included 37 tornadic thunderstorm days, 37 major severe thunderstorm days, 37 minor severe thunderstorm days and 37 days with non-severe thunderstorms. The data on the tornadoes and severe thunderstorms were obtained from Storm Data (U.S. Department of Commerce 1989-1993). The distributions of these thunderstorm days by month and by year are shown in Fig. 1. LaPenta et al. (2000) (hereafter referred to as LMM00) describes the development of 2 equations (Table 2), one to forecast hail size and the second, to forecast hail severity, using the same data set. Hail severity is a function of both the maximum observed hail size and the number of reports of severe hail[1]. This new study uses the data set developed in ML97 and LMM00 to examine additional forecast indices not previously available, and to re-examine in more detail several parameters previously studied. In ML97, storm-relative helicity (s-rH) was the highest correlated parameter with severe weather as defined in that study. During recent years, two different approaches, the helicity perspective and shear perspective, have evolved which are used to explain supercell dynamics. A large number of shear parameters will be evaluated to see if they are better correlated with severe weather than s-rH. Surface based Convective Available Potential Energy (CAPE) was also an important forecast parameter in the previous work. In this study, mean parcel CAPE and CAPE normalized for storm depth will be evaluated. Downward Convective Available Potential Energy (DCAPE), an estimate of the kinetic energy available to a downdraft parcel due to negative buoyancy, may be an important parameter in assessing the potential for damaging straight line winds and for determining low-level supercell structure. Its relationship to severe weather will be examined. The utility of a number of other forecast parameters including atmospheric lapse rates through various layers, atmospheric lapse rates through various layers, storm-relative wind flow and the lifted condensation level (LCL) will also be studied.

[1] The categories were subjectively determined based on the principle that an extreme hail day must have both a large number of events and very large hail reported. A major hail day must be the result of a large number of reports of relatively small hail, or a few reports of very large hail. Finally, a minor hail day must be the result of a few reports of relatively small hail. A minor hail day was a day with either five or less reports of severe hail less than 1.00 inch, or one or two reports of hail 1.00 inch to less than 1.75 inches. A major hail day was defined as a day with six or more reports of severe hail less than 1.00 inch, 3 to 14 reports of hail 1.00 inch to less than 1.75 inches, or up to five reports of hail 1.75 inches or greater. An extreme hail day was defined as a day with six or more reports of hail 1.75 inches or greater, or more than 15 reports of hail 1.00 inch or greater.

2. DATA AND METHODOLOGY

This study uses the data set developed in ML97 and used in LMM00. For each of the 148 days sampled, a sounding was constructed to approximate the synoptic scale atmospheric conditions at the time of the event. Actual atmospheric soundings from across the northeastern United States were examined, and the sounding that was considered to be most representative of the airmass over the location where tornadoes, severe or non-severe thunderstorms occurred was selected. This sounding was then modified using the Skew-T Hodograph Analysis and Research Program (SHARP) (Hart and Korotky 1991) for observed surface temperature, dewpoint temperature, and wind from a surface observation site near the location and at the time of the thunderstorms. On a few occasions, additional subjective modifications were made if significant thermal advection aloft was evident, or changes to the vertical wind profile were warranted due to wind speed and/or direction changes aloft. In this work, SHARP and a new sounding analysis program, WXMAGIC, (Center 1998) were used to generate a number of parameters used in severe weather forecasting. These parameters were then correlated with the observed severe weather category (tornadic, major severe, minor severe and non-severe) in order to assess their utility in forecasting severe weather.

The limited spatial and temporal sampling by the NWS radiosonde network and the highly variable nature of the atmosphere make it difficult to create soundings that accurately represent the state of the atmosphere at the time of a particular event. If temporal and spatial restrictions are too strict, it will be difficult to come up with a statistically significant number of cases (Brooks et al. 1994). The goal of this study was to evaluate the general conditions that produce severe thunderstorms and tornadoes using information that is routinely available to forecasters. In order to maximize the size of the data set, strict temporal and spatial constraints were not placed on the use of observed soundings. Atmospheric conditions at the time of an event, or series of events, were approximated to the best degree allowed given data limitations. However, prior to the final selection of the 148 cases used in this study, a number of events were eliminated from consideration, because missing or incomplete data made analysis of the event impossible. Brooks et al. (1994) discuss in detail the use of, and limitations of, such an approach.

3. RESULTS

a. Helicity versus vertical wind shear

Observational studies and numerical simulations indicate that wind shear is important in determining storm type and severity of convective storms. Increased speed and veering of environmental winds with height are favorable for the development of severe storms and tornadoes (e.g., Fawbush and Miller 1954, Weisman and Klemp 1984). The tilting of horizontal vorticity inherent in the vertically sheared flow produces rotating, supercell thunderstorms (Rotunno 1981, Davies-Jones 1983). S-rH (Davies-Jones et al. 1990) represents the summation of streamwise vorticity through the storm inflow layer and gives a measure of the rotational potential of a thunderstorm updraft. Quasi-steady, rotating updrafts are a characteristic of supercell thunderstorms. While supercells do not produce all severe weather and tornadoes, they tend to produce more intense tornadoes and more significant severe weather than non-supercell severe storms. In this study, storm structure was not considered in defining severe weather categories.

During the past decade, two different approaches have evolved which are used to explain supercell dynamics; the helicity perspective and the shear perspective. The vertical wind shear perspective emphasizes the physical processes by which an updraft interacts with the ambient vertical shear to produce a quasi-steady rotating storm (Weisman and Rotunno, 2000). The helicity view assumes the existence of a steady-state, propagating storm, and then considers what storm motion leads to updraft rotation. Weisman and Rotunno (2000) discuss this issue in detail.

In ML97, storm-relative helicity in the lowest 3 km of the atmosphere was the parameter best correlated (correlation .60) with severe weather category. A limited number of shear parameters were tested but showed significantly lower correlation than s-rH. In this study, shear values, both positive and total, were calculated for many layers from the surface to 6 km above ground level (AGL). Positive shear represents the sum of 500 m hodograph segments showing clockwise curvature through a given depth (Hart and Korotky 1991). The correlation of various shear measurements is shown in Table 3. The 0-1 km positive shear is the shear parameter best correlated (correlation -.42) with severe weather. The positive shear shows a slightly higher correlation than the total shear for a corresponding layer, and as the depth of the layer increases, the correlation decreases. The calculation of s-rH is dependent on storm motion. Any errors in estimating storm motion could have a significant impact on s-rH, especially if lower tropospheric wind fields are strong. In ML97, s-rH was calculated using observed storm motion. S-rH was recalculated assuming the observed storm motion was not known, using a default storm motion 30° to the right of the mean 0-6 km wind with 75 percent of its magnitude. The correlation of s-rH (based on the default storm motion) with severe weather dropped from -.60 to -.48, which is still higher than any of the shear parameters tested.

Studies by Johns and Doswell (1992), Lazarus and Droegemeier (1990) and LaPenta (1992) have shown that there is a relationship between s-rH (or shear) and instability that contributes to the development of supercells and tornadoes. Supercells and tornadoes can occur with marginal (large) s-rH and large (weak) instability. CAPE gives a measure of instability by integrating the positive buoyancy of a rising parcel. The energy-helicity index (EHI) (Hart and Korotky 1991) combines s-rH and CAPE into a single index according to the equation:

$$EHI = (CAPE * +s\text{-}rH) / 160000 \qquad (1)$$

where +s-rH is the positive storm-relative helicity in the 0-2 km (AGL) layer. A similar index can be developed using a shear parameter in equation (1) to replace helicity. Three energy-shear indices (ESI) are tested.

$$ESI_1 = (CAPE * 0\text{-}1 \text{ km pos shear}) \qquad (2)$$

$$ESI_2 = (CAPE * 0\text{-}6 \text{ km pos shear}) \qquad (3)$$

$$ESI_3 = (CAPE * 0\text{-}6 \text{ km total shear}) \qquad (4)$$

The EHI has a correlation with severe weather of -.58 while the ESI_1, ESI_2, and ESI_3 have correlations of -.52, -.538 and -.542 respectively. It is interesting to note that while the 0-6 km total shear has the lowest correlation of any shear parameter tested, it has the best correlation when combined with CAPE, and compares favorably with the EHI. The EHI in this study was based on observed storm motion. If the EHI is recalculated using s-rH based on a default storm motion 30° to the right of the mean 0-6 km wind with 75 percent of its magnitude, its correlation drops to -.51. Fig. 2 contains box and whisker plots of EHI versus severe weather category and ESI_3 versus severe weather category. The mean EHIs for the tornadic, major severe, minor severe and non-severe categories are 1.66, .57, .34, and .11 respectively while for the ESI_3s the means are 8.28, 8.39, 5.21, and 3.22. (Table 4 includes means, medians and standard deviations for each severe weather category.) While the EHI shows good separation between the tornadic and major severe cases, the values for the ESI_3 are nearly equal. This suggests that the EHI does a better job than the ESI_3 of discriminating tornadic and major severe events. Increasing ESI_3 indicates an increasing threat of significant severe weather (either a major severe or tornadic event). Fig. 3 is a plot of severe weather category as a function of the 0-6 km total shear and CAPE. The tornadic and major severe weather events have been combined into a single category. Combinations of CAPE and shear above the solid line in Fig. 3 indicate a high probability of significant severe weather.

b. Instability

Instability is a necessary ingredient in the development of severe thunderstorms. The lifted index (LI) estimates instability by comparting the temperature of a lifted parcel to the ambient temperature at a single level, usually 500 hPa. CAPE should give a better estimate of the instability of a rising parcel, since it incorporates data at all levels of a sounding. Interestingly, the LI actually has a slightly better correlation (-.55) with severe weather category although CAPE had a slightly higher correlation with hail size and severity. CAPE is greatest in the major severe cases (mean 2273 J/kg) and has an overall correlation with severe weather category of -.52. In the tornadic, minor severe and non-severe cases CAPE is 1856 J/kg, 1421 J/kg and 928 J/kg respectively. CAPE is recalculated in this study using average conditions in the lower 50 hPA of the troposphere. By using average conditions over the lowest 50 hPA, it was hoped that better representing overall boundary conditions would lead to a higher correlation with severe weather. However, the correlation decreased to -.44.

The distribution of CAPE through the atmosphere might be important in assessing severe weather potential (Blanchard 1998). A given CAPE distributed through a relatively shallow layer might be more significant that the same quantity distributed through a deep layer. CAPE normalized for the depth of the storm layer is calculated according to the following equation:

$$CAPE_n = CAPE\ (\ EL - LFC) \qquad (5)$$

where $CAPE_n$ is normalized CAPE, EL is the equilibrium level (an estimate of the height of the storm top) and LFC is the level of free convection (an estimate of the height of the storm base). The correlation of $CAPE_n$ with severe weather category was -.49, slightly less than the -.52 correlation of CAPE.

The lapse rate through the atmosphere may help identify areas of quality instability, and forecasters in the Northeast typically look at the 850 to 500 hPa lapse rates in assessing severe weather potential. Lapse rates for various layers, at least 200 hPa thick, between 850 and 500 hPa were calculated and correlated with severe weather category. The 850 hPa to 500 hPA lapse rate had a correlation of -.18, while the layer with the highest correlation to severe weather was 800 to 600 hPa with a correlation -.26. The maximum observed lapse rate in any 200 hPa layer was calculated, but it produced a correlation of only -.16. While these correlations are not high, it does not guarantee that layer lapse rates are not important, at least on certain occasions. Forecasters have long recognized that the presence of an elevated mixed layer is an important feature of the severe weather environment especially across the Great Plains (Lanicci and Warner 1991). The presence of this mixed layer results in a large region of instability aloft if a parcel is lifted to its level of free convection. Figure 4 is an example of a sounding, taken on 29 May 1995, (modified for observed surface temperature and dewpoint) containing an elevated mixed layer, on a day when an F2-F3 tornado was observed in eastern New York and western Massachusetts. While the steep lapse rate observed in this sounding may be important in forecasting a significant severe weather event, it may occur infrequently, and thus the poor overall correlation of lapse rate with severe weather.

c. Downward convective available potential energy (DCAPE)

DCAPE represents a downdraft equivalent of CAPE. It is defined as the maximum increase in kinetic energy per unit mass that could result from evaporatively cooling of the air within a parcel as it descends from some source height to the ground (Gilmore and Wicker 1998). It is calculated by integrating the negative temperature perturbations over the downdraft path. On a SKEW-T diagram, it is proportional to the graphical area between the wet-bulb potential temperature of downdraft air and the environmental temperature curve. DCAPE could be a useful severe weather forecast parameter for two reasons. Theoretically, the greater the DCAPE, the greater the potential downdraft strength, and the greater the potential for damaging winds if the downdraft reaches the surface. Also, DCAPE is related to thunderstorm outflow strength and Brooks et al. (1994) demonstrated that low-level outflow strength may have been related to tornadic potential in a study of 90 storms. In this study, DCAPE is calculated using the WXMAGIC sounding analysis program (Center 1998).

There is little correlation of DCAPE with severe weather category as defined in this study. This may be due to a number of factors. First, in this study, the major and minor severe weather categories are defined based on the number of severe weather events. A major severe event could be composed primarily of hail events or mostly of wind damage reports. Downdraft characteristics for each event could be different. In addition, storm structure was not taken into account when classifying events. Finally, Gilmore and Wicker (1998) stated that assumptions inherent in the definition of DCAPE prevent it from providing a good measure of downdraft strength. Their study showed that the entrainment of environmental air dilutes the downdraft and thus increases in kinetic energy due to evaporative cooling are less than predicted by DCAPE. Still, there is some indication that DCAPE could be a useful severe weather forecast parameter. Figure 5 is a box and whisker plot showing severe weather category as a function of DCAPE. It shows the DCAPE for major severe weather events tends to be higher than for the other categories. The mean DCAPE for major severe cases is 353 J/kg, while for tornadic, minor severe, and non-severe events is 243 J/kg, 274 J/kg, and 264 J/kg respectively. (Table 4 includes means, medians and standard deviations for each category.) Perhaps, a more realistic formulation of DCAPE and a classification of severe weather categories that includes the type of severe weather, might yield better results.

d. Lifted condensation level

Rasmussen and Blanchard (1998) and

Edwards and Thompson (2000) observed that supercells above a deeply mixed, relatively dry convective layer with high LCLs often do not produce tornadoes, even in environments that would otherwise be considered favorable. They hypothesized that in these cases, greater evaporative cooling of moist downdraft air would lead to outflow dominated storms. Edwards and Thompson determined LCLs from RUC-2 model soundings near the location of supercell storms. They found that LCLs for supercells producing strong and violent (F2 or greater) tornadoes were about half that of nontornadic supercells. LCLs for weak (F0 or F1) tornadoes were somewhat lower than for nontornadic supercells. In this study, data are observational and not based on model output, events are not restricted to supercell cases, and tornadoes are not stratified by intensity. Fig. 6 is a box and whisker plot of LCL as a function of severe weather category for the 148 cases in this study. A similar pattern emerged as the LCLs in the tornadic cases were lower than those in the other categories. The mean LCL for tornado cases was 918 m with the mean LCLs for major severe, minor severe and non-severe cases 1214 m, 1075 m and 1245 m respectively. (Table 4 includes means, medians and standard deviations for each category.) The mean LCL in the major severe cases was higher than in the minor severe cases possibly indicating that a greater evaporative cooling potential in the major severe cases lead to stronger downdraft induced winds at the surface.

e. Storm-relative wind flow

Brooks et al. (1994) looked at mid-level storm-relative flow in comparing tornadic and nontornadic mesocyclones. They hypothesized that if mid-level storm-relative winds are too weak relative to the strength of the mesocyclone, the bulk of precipitation will fall near the updraft. In this case, low-level mesocyclogenesis is rapid but very short-lived as rain-cooled downdraft air quickly cuts off inflow. If rain is blown away from the updraft by stronger mid-level storm-relative winds, the cool downdraft does not cut off the inflow. However, if the storm-relative flow is too strong and the rain is blown too far away, there may not be baroclinic generation of low-level vorticity which is thought to be important in low-level mesocyclogenesis (Brooks et al. 1994). Thompson (1998) used Eta model soundings to examine storm-relative winds at the surface, 500 hPa and 250 hPa associated with tornadic and nontornadic supercells. The 500 hPa storm-relative winds did the best job of distinguishing tornadic and nontornadic supercells. They showed that the 500 hPa storm-relative wind speed has a distinct lower bound of approximately 8 m s^{-1} for the tornadic supercells, while differences between surface and 250 hPa storm-relative wind speeds for tornadic and nontornadic supercells were much less pronounced (Thompson 1998).

In this study storm-relative and environmental winds are examined at 4500 m, 5500 m, 6500 m and 7500 m AGL and correlated with severe weather category. Table 5 shows the correlation coefficients for each level. Environmental winds are better correlated with severe weather category than storm-relative winds at every level. Storm-relative winds at 4500 m, which is somewhat below the 500 hPa level, show the highest correlation with severe weather category. The 148 cases used in this study are not restricted to supercell events, and thus the results are not directly comparable to Thompson (1998). Still, tornadic events did show, on average, higher storm-relative mid-level environmental winds than the other three categories. Figure 7 is a box and whisker plot of 4500 m storm-relative wind speed by severe weather category. (Table 4 includes means, medians and standard deviations for each category.) Storm-relative winds at 4500 m AGL are considerably stronger in the tornado events (mean 7.9 m s^{-1}) when compared to the major severe, minor severe and non-severe categories (means 5.6 m s^{-1}, 4.8 m s^{-1} and 6.1 m s^{-1} respectively). At 5500 m AGL, closer to 500 hPa, the mean storm-relative wind for the tornado cases is 8.9 m s^{-1}. However, the mean value of 8.9 m s^{-1} for the tornadic cases is close to Thompson's (1998) lower bound (8 m s^{-1}) for tornadic supercells.

4. Discussion

Forecasters at the NWS forecast office at Albany have found that the equations developed in ML97 and LMM00 to be useful tools in assessing the potential for severe convection. The equations are conditional in nature and thus, if thunderstorms are not expected or do not form, then the output from the equations has no meaning. If analyses of observed data and numerical model output indicate thunderstorms are possible, or if thunderstorms are already occurring, then the equations should provide useful guidance. In addition, when using the equations with numerical model output, systematic errors of the model will be reflected as systematic errors in the forecasts from the equations. However, if forecasters are aware of model errors or biases for their area, they can subjectively adjust the model output, thereby reducing the impact of this limitation. Finally, even though these equations should only be applied in the specific geographic area for which they were derived, the methods used to develop them can be applied elsewhere.

This study uses the data set developed in the previous papers to examine additional forecast indices not previously available, and to re-examine in more detail several parameters previously studied. S-rH is the parameter best correlated with severe weather category and is far superior to any shear parameter tested. However, s-rH assumes the storm motion is known. If a default storm motion was used, s-rH has only a marginally better correlation than the best shear parameter. The 0-1 km positive shear is the highest correlated shear parameter (-.42) and significantly higher than the correlation of the 0-6 km total shear (-.14). When the 0-6 km total shear is multiplied by CAPE to produce an energy shear index (ESI_3), the correlation is higher than the correlation of a similar index using the 0-1 km positive shear (ESI_1) and almost as high as the EHI (which assumes storm motion is known).

Attempts to recalculate CAPE in order to produce a better measure of instability were unsuccessful. CAPE based on lifting a surface parcel is better correlated with severe weather category than CAPE calculated by lifting a parcel based on conditions averaged over the lower 50 hPa of the atmosphere, and CAPE normalized for storm depth. The lapse rate between 800 hPa and 600 hPa is the lapse rate best correlated with severe weather, although the overall correlation was poor. DCAPE represents a downdraft equivalent of CAPE. While it shows an overall poor correlation with severe weather category, major severe weather events have a significantly higher DCAPE than the other 3 categories. Storm-relative winds for tornadic events are higher than in the other 3 categories, although the average for all tornado cases at 5500 m (close to 500 hPa) is near the lower bound for tornadic supercells as suggested by Thompson (1998). A large number of other parameters were examined, but have not been presented.

Many studies cited in this paper dealt primarily with supercell storms. Severe weather in this study was categorized into 4 classes based on the presence of tornadoes, or the number of nontornadic severe weather reports. Tornado cases were not restricted to supercellular storms. A study by LaPenta et al. (2000) indicated that about half of the tornadoes in the Northeast were not associated with supercells. Also, the type of severe weather report, large hail or damaging winds, was not taken into account in determining whether an event was assigned to the major severe or minor severe category. Stratifying the severe weather categories in a different manner could yield different results as different dynamic and thermodynamic processes may be involved in thunderstorms that produce primarily large hail and thunderstorms that produce mainly damaging winds.

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Table 1. Equation for forecasting thunderstorm severity

$$S = 4.94 - .00078\,(CAPE) - .0040\,(MWND) + .18\,(EHI) - .027\,(SPD) - .0065\,(s\text{-}rH)$$

where S is storm severity, CAPE is convective available potential energy, MWND is the maximum wind observed in the sounding, EHI is the Energy-helicity Index (EHI), and s-rH is storm-relative helicity.

If S is $\geq$ 3.5	forecast a non-severe event
If S is $\geq$ 2.5 but <3.5	forecast a minor severe event
If S is $\geq$ 1.5 but <2.5	forecast a major severe event
If S is <1.5	forecast a tornadic event

Note: equation is conditional, assuming thunderstorms occur.

Table 2. Equations for forecasting hail size (diameter in inches) (SIZE) and hail severity category (CAT)

$$\text{SIZE} = -.77 + .032\,(\text{EQLV}) + .00048\,(\text{CAPE}) + .024\,(\text{TT}) + .0023\,(\text{s-rH}) - .12\,(\text{WBZCAT}) + .055\,(\text{850T})$$

$$\text{CAT} = .15 - .14\,(\text{EQLV}) - .50\,(\text{WBZCAT}) + .0018\,(\text{CAPE}) + .080\,(\text{TT}) + .0061\,(\text{s-rH}) + .20\,(\text{850T})$$

where EQLV is the equilibrium level in thousands of feet, WBZCAT is the wet-bulb zero category[2], CAPE is convective available potential energy, TT is total totals, s-rH is storm-relative helicity, and 850T is the 850 hPa temperature in °C.

If CAT is <3.5	forecast no severe hail
If CAT is ≥ 3.5 but <5.5	forecast a minor hail event
If CAT is ≥ 5.5 but <7.5	forecast a major hail event
If CAT is ≥ 7.5	forecast an extreme hail event

Note: equations are conditional, assuming thunderstorms occur.

[2] WBZCAT is 0 for a wet-bulb zero (WBZ) between 9100 and 10900 ft, 1 for a WBZ between 8100 and 9000 ft or between 11000 and 11900 ft, 2 for a WBZ less than or equal to 8000 ft or between 12000 and 12900 ft, 3 for a WBZ between 13000 and 13900 ft and 4 for a WBZ greater than or equal to 14000 ft.

Table 3. Correlation of various shear related parameters and s-rH with severe weather category

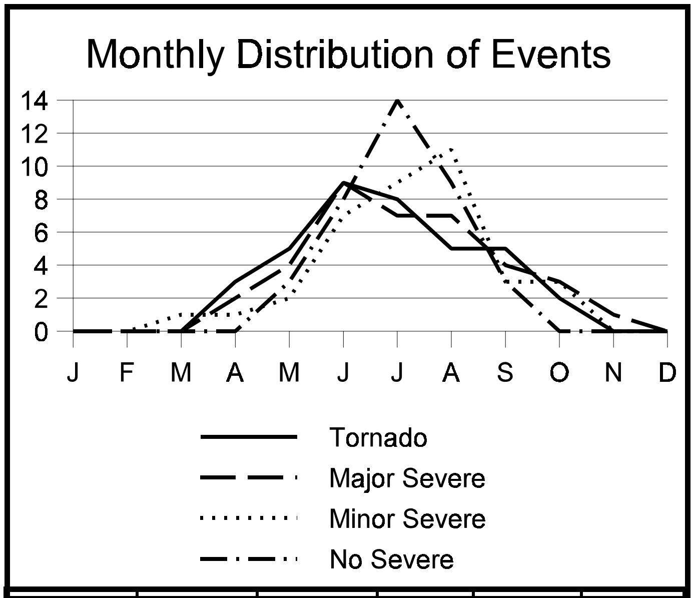
Positive shear	0-1 km	-.421
	0-2 km	-.41
	0-3 km	-.38
	0-4 km	-.36
	0-5 km	-.36
	0-6 km	-.29
Total Shear	0-1 km	-.417
	0-2 km	-.34
	0-3 km	-.26
	0-4 km	-.26
	0-5 km	-.20
	0-6 km	-.14
0-3 km s-rH		-.60
0-3 km s-rH using default storm motion		-.48
EHI		-.58
ESI_1		-.52
ESI_2		-.538
ESI_3		-.542
EHI using default storm motion		-.51

Table 4. Mean, median and standard deviation (sd) of various parameters, grouped by severe weather category.

Parameter	Severe weather category 1	2	3	4	
EHI					
mean		1.67	0.57	0.34	0.11
median	1.35	0.47	0.24	0.06	
sd	1.34	0.54	0.34	0.12	
ESI_3					
mean		8.28	8.39	5.21	3.22
median	7.51	8.05	4.64	2.73	
sd	3.79	2.95	3.47	2.05	
DCAPE (j/kg)					
mean		243	353	274	264
median	215	338	276	274	
sd	147	121	125	132	
LCL (m)					
mean		918	1214	1075	1245
median	845	1234	990	1275	
sd	436	352	416	499	
4500 m s-rWIND (ms^{-1})					
mean		7.9	5.6	4.8	6.1
median	7.8	4.7	4.1	5.2	
sd	4.4	3.0	3.9	3.8	

Table 5. Correlation of storm-relative and environmental winds with severe weather category

Height (m -AGL)	Correlation coefficient Storm relative	Environmental
4500	-.17	-.38
5500	-.12	-.33
6500	-.03	-.22
7500	-.12	-.13



	Tor	Maj	Min	Non	Total
1989	4	8	4	2	18
1990	8	4	7	13	32
1991	4	11	12	10	37
1992	8	7	6	8	29
1993	13	7	8	4	32

Figure.1. The monthly distribution of thunderstorm days used in this study for each of the 4 severe categories (upper portion). The lower portion shows the distribution of thunderstorm days by year for each of the 4 severe categories.

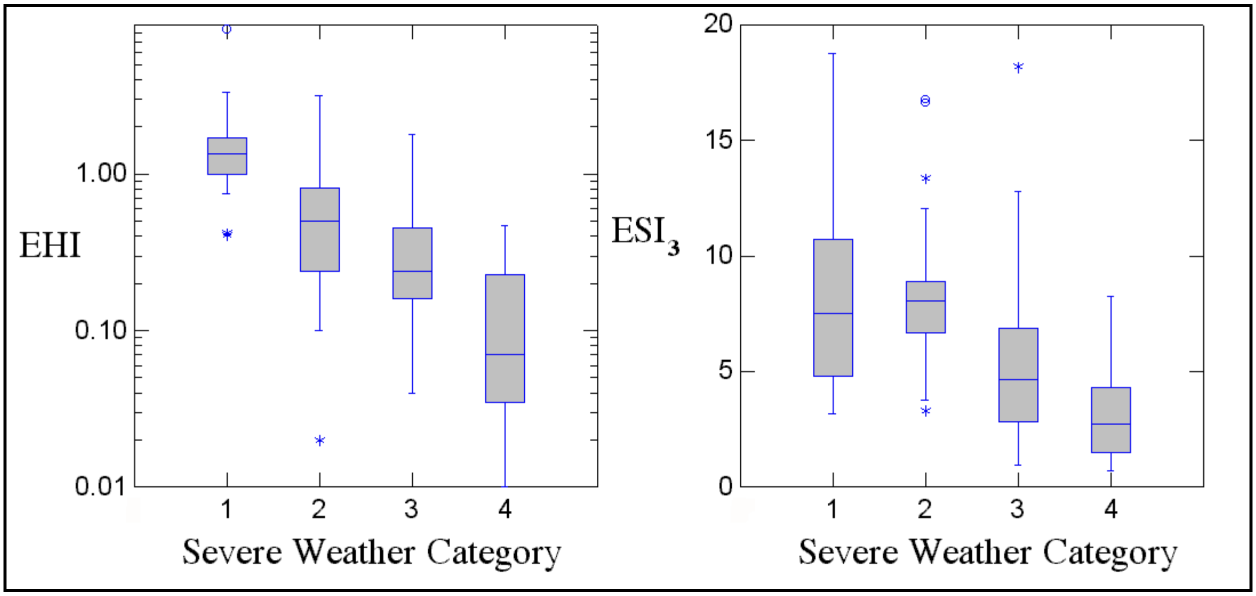


Figure 2. A box and whisker plot of EHI (left) and ESI_3 (right) by severe weather category. The horizontal line at the center of the box represents the median value, while the ends of the box represent the first and third quartile. The vertical lines extending from the ends of the box represent the range of values except where outliers (asterisk) and far outliers (small circle are noted.

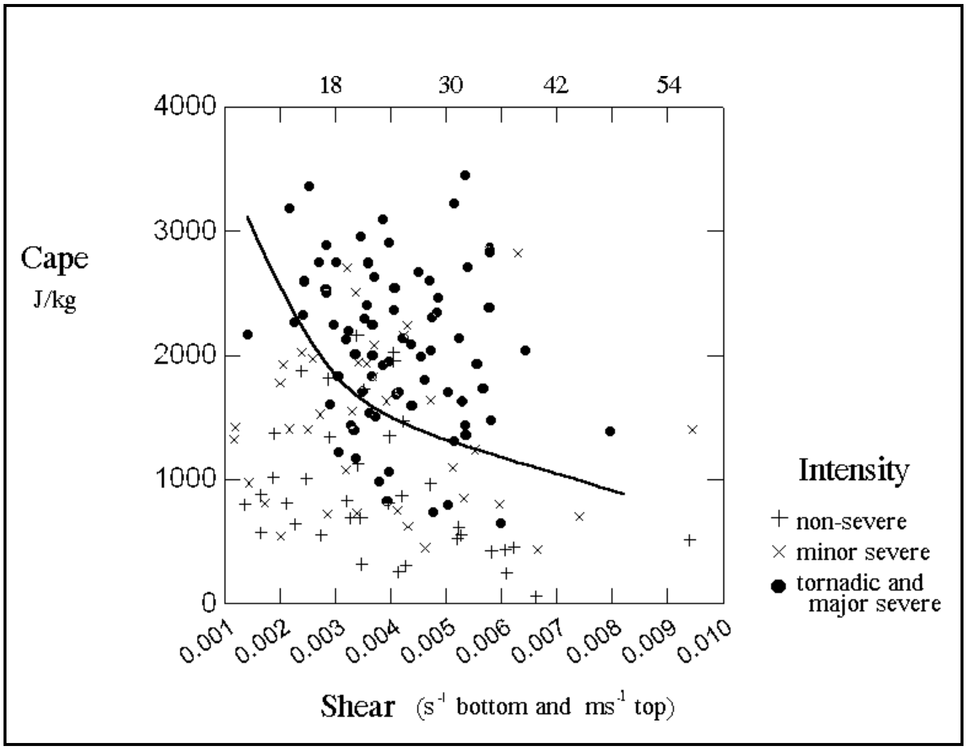


Figure 3. A plot of CAPE versus 0-6 km total shear. Tornadic and major severe events were combined into a single category. Combinations of CAPE and shear above the solid line indicate a high probability of significant severe weather.

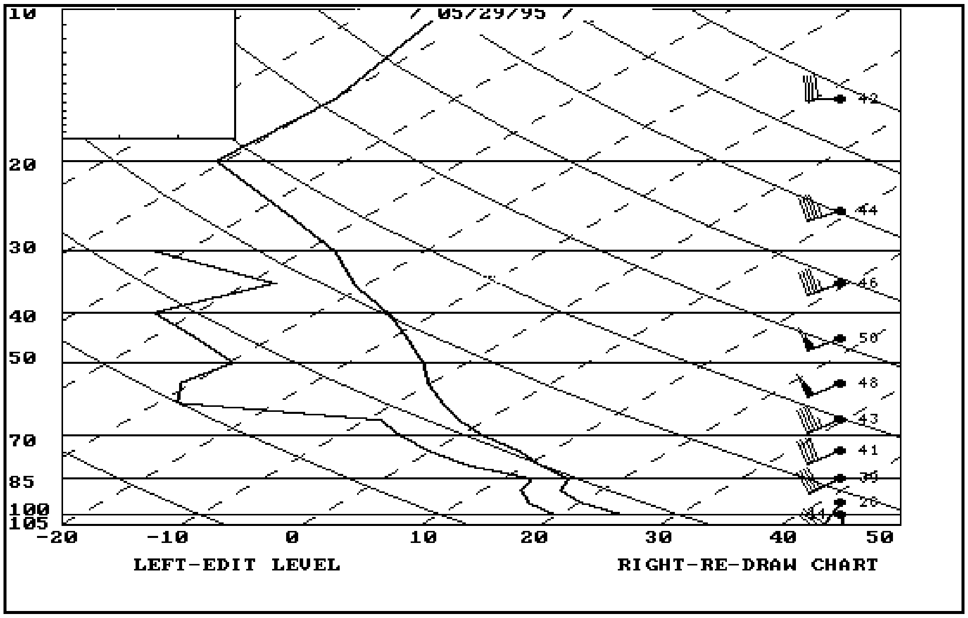


Figure 4. A sounding taken on 29 May 1995 (modified for observed surface temperature and dewpoint) containing an elevated mixed layer, on a day when an F2-F3 tornado was observed in eastern New York and western Massachusetts.

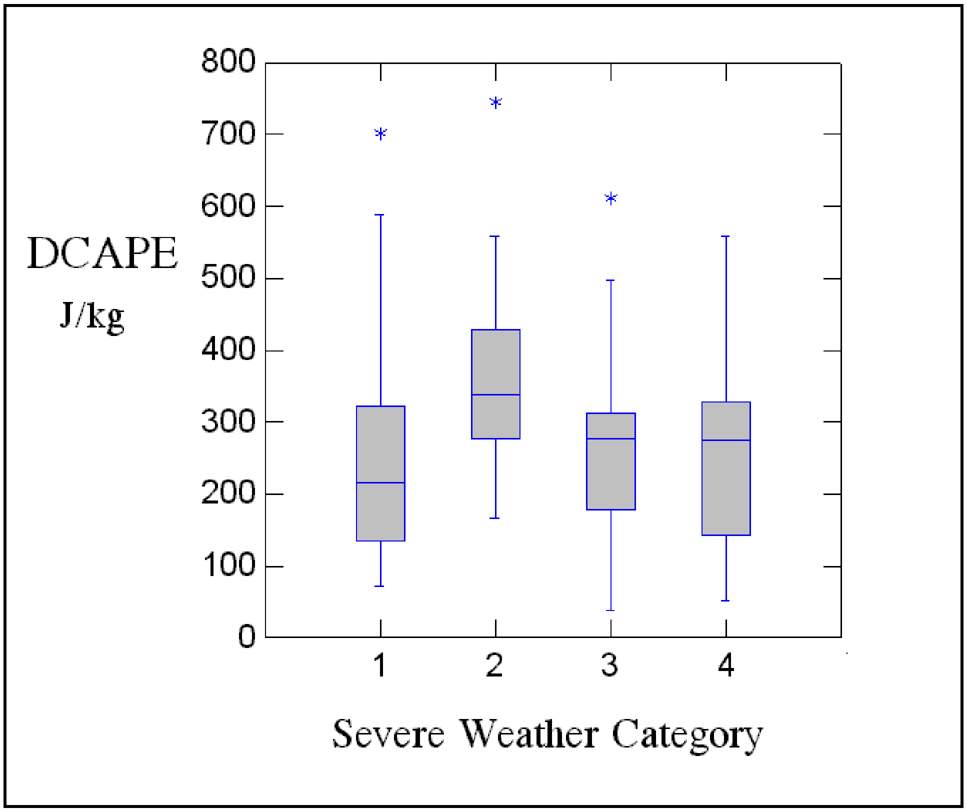


Figure 5. A box and whisker plot of DCAPE by severe weather category.

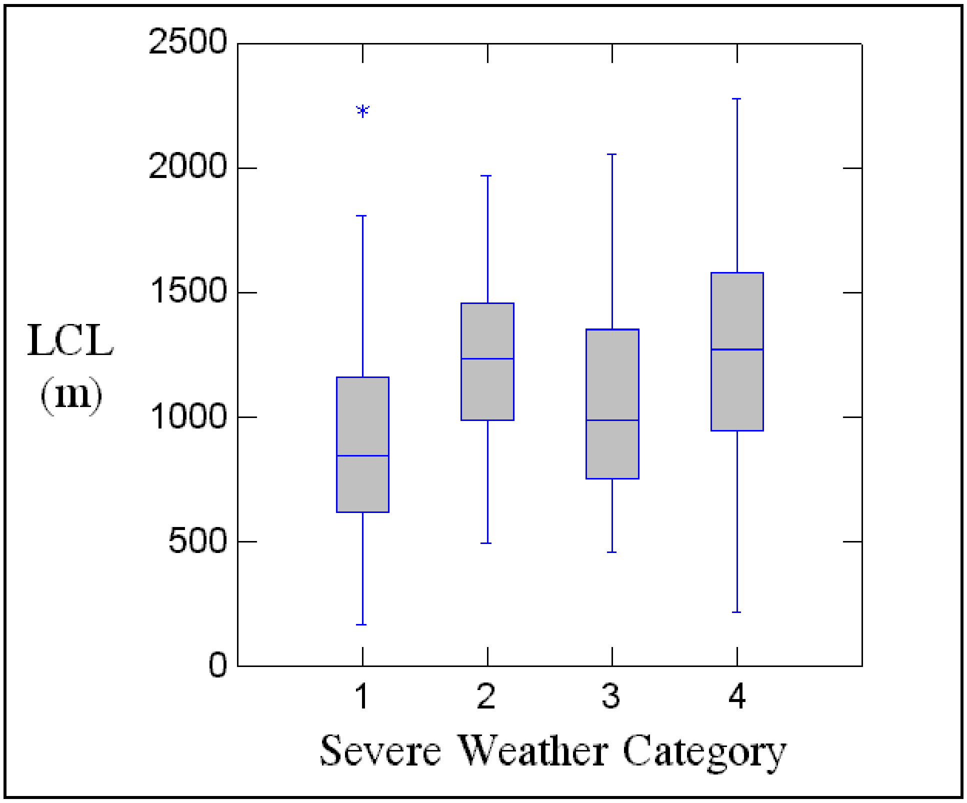


Figure 6. A box and whisker plot of LCL by severe weather category.

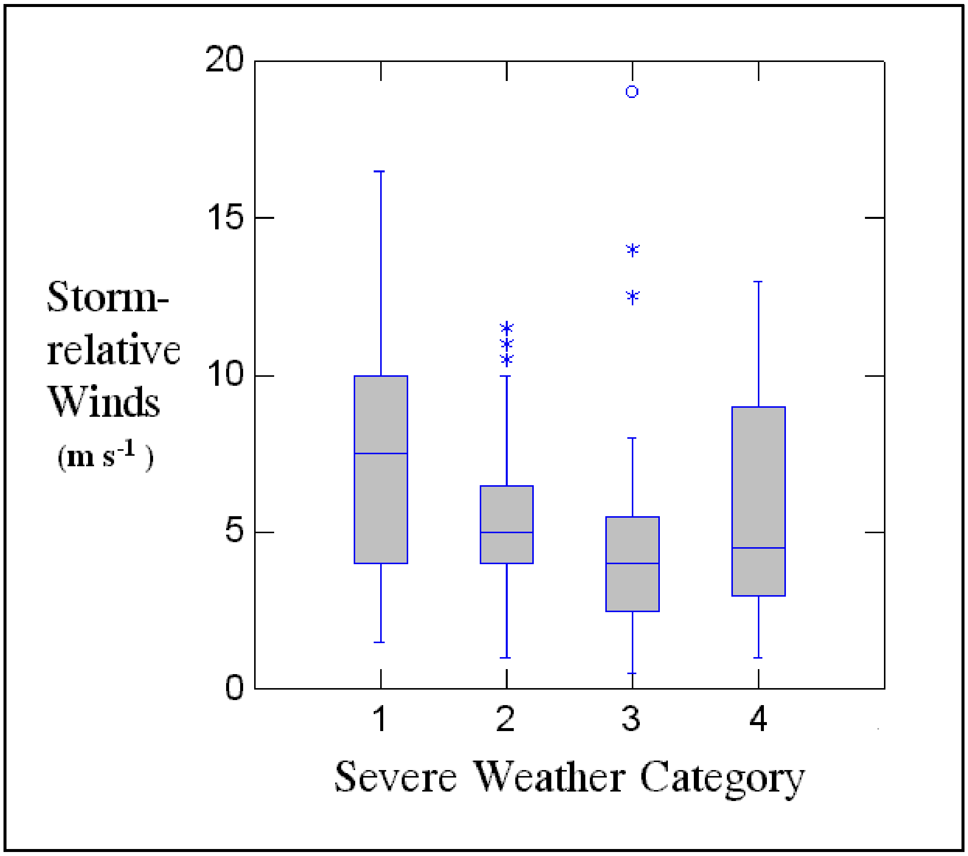


Figure 7. A box and whisker plot of 4500 m AGL storm-relative wind by severe weather category.